MINIMIZING WOOD SHRINKAGE AND SWELLING

Treatment with Sucrose and Invert Sugar

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MINIMIZING WOOD SHRINKAGE AND SWELLING

Treatment with Sucrose and Invert Sugar[1]

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Abstract

The treatment of wood with sucrose and invert sugar solutions is shown to greatly reduce the subsequent shrinkage. Shrinkage takes place when the relative vapor pressure under which the specimens are dried is less than the relative vapor pressure of the treating solution at the concentration attained when evaporation has proceeded to the fiber-saturation point. The large reduction in shrinkage to the oven-dry condition is due to sugar being deposited within the swelling structure. This reduction in shrinkage can be calculated from the partial specific volume of sugar in the concentration attained within the swollen structure on the basis of this concentration becoming equal to the corresponding bulk concentration. Invert sugar reduces the dimension changes of wood to a greater extent than sucrose and should serve as a good antishrink agent under conditions which will not be too conducive to leaching of the sugar from the wood.

The treatment of wood with sugar solutions dates back to the Powell patent of 1904 (6). Powell did not consider the stabilization of the dimensions of the wood, but was rather interested in the prevention of decay. The following year Tiemann showed that the sugar materially reduces the shrinkage of wood as a result of the retention of the solution. Further measurements made by him in 1928 are summarized by Hunt (4). Antishrink efficiencies, the reduction of the dimension changes of the treated specimens per unit dimension change of the controls, of better than 70 percent were obtained between the saturated and the air-dry condition for specimens treated with concentrated sugar solutions.

This research was undertaken to determine more definitely the effect of sugar treatment upon the shrinking of wood and to find out if the shrinkage is governed by the same principles as were found to hold for salt treatment (8). It was also desirable to determine the dimension stabilization of wood treated with

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invert sugar compared to that treated with sucrose, as invert sugar had been shown by Dittmar (3) to be considerably more hygroscopic than sucrose and by Leete (7) and Pike (5) to increase the moisture retention of paper when used in only moderate concentrations.

Experimental Procedure

Thin sections of Northern white pine 2 mm. in the fiber direction by 4.4 cm. in the other two directions were used for these measurements. Oven-dry sections were weighed and the tangential and radial dimensions determined. The sections were then soaked in water or sugar solutions, with intermittent applications of suction to remove the air. After soaking for 3 days to permit diffusion of the sugar into the fine structure, the sections were brought to equilibrium with the decreasing relative vapor pressures 91.2, 75.8, 54.1, 32.9, and 11.7 percent obtained by drawing air at room temperature (approximately 25° C.) through towers containing saturated solutions of $BaCl_2$, NaCl, $MnCl_2$, $MgCl_2$, and LiCl, respectively, and then through open dishes of the saturated salt solutions placed on the bottom of vacuum desiccators which served as the humidity chambers. Air was drawn through the system under a reduced pressure of about half an atmosphere at the approximate rate of 10 liters per hour. Under these conditions the theoretical relative vapor pressures in equilibrium with the saturated salt solutions were virtually attained. Experiments showed that the 2-week humidification period used for conditioning was ample for obtaining equilibrium. The sections were then dried at room temperature over P_2O_5 for 2 weeks, followed by oven drying over P_2O_5 for 3 days at 110° C. The sections were weighed and measured after each of these periods.

Shrinkage-relative Vapor Pressure Relationships

The sum of the tangential and the radial shrinkage in percent (the approximate surface shrinkage) from the soaked condition to equilibrium with the various relative vapor pressures are plotted against the relative vapor pressure in Figure 1 for the average of 3 water-saturated sections and 3 sections completely filled with each of 4 different concentrations of sucrose and invert sugar solutions. The relative vapor pressure effective in drying over P_2O_5 at room temperature under the conditions of these measurements was estimated from the shrinkage occurring from equilibrium with P_2O_5 to the oven-dry condition, using the moisture content-relative vapor pressure relationship and the linear moisture content-shrinkage relationship. Completely water-swollen sections were found to swell only 0.1 percent further on a surface swelling basis when enough sugar was added to the water in which the sections were soaking to bring the equilibrium concentration of liquid up to 50 grams per 100 cc. of solution. The shrinkage of the sugar-treated sections on drying can thus be referred to the shrinkage of the controls without involving a green dimension correction.

Figure 1 shows that the treatment of the wood sections with sugar solutions depresses the equilibrium shrinkage in a similar manner to that previously found for treatment with salts (8). The zero shrinkage and zero relative vapor pressure points represented by square symbols correspond to the similar circular symbols and represent calculated points. The zero shrinkage points were calculated on the basis of the concentration of the solutions virtually attaining the same concentration within the swelling structure of the cell wall as the bulk concentration. The completely saturated sections contained 214 percent water on the basis of the dry weight of the wood, while the fiber-saturation point on the same basis from the shrinkage data (fig. 2) is 28.5 percent. In evaporating the free water from the wood the volume is thus decreased 7.5 fold. As the dimensions of the wood are virtually unaffected by the presence of the sugars, this last figure represents the increase in concentration of sugar solution occurring on drying a saturated section to the fiber-saturation point. The relative vapor pressure in equilibrium with this concentration was obtained from the relative vapor pressure-concentration relationships for sucrose given in the International Critical Tables, and the similar relationship for invert sugar given by Dittmar (3). Initial concentrations of sucrose of 12.5 grams per 100 cc. of solution and above give concentrations above saturation upon evaporation. The sucrose will thus be deposited in the cell cavities, even if diffusion into the swollen structure were complete. The saturated solution gives a relative vapor pressure of water of 83.5 percent. Invert sugar is considerably more soluble than sucrose; hence, in the higher concentrations it shows a greater depression of the relative vapor pressure. There is no definite solubility limit for invert sugar, there being a gradual transition from a viscous solution to a glass. In concentrations above approximately 85 percent, diffusion should be negligibly small, however, so that this has been considered as the limiting concentration for these calculations.

The shrinkage to the oven-dry condition in all cases is retarded by the deposition of sugar in the swollen structure. The reduction in the shrinkage can be calculated from the partial specific volume of the sugar in the concentration attained within the cell wall, if diffusion into the swollen structure on drying is considered complete. This condition seems to be approached under the slow drying conditions used. In the case of the lower concentrations the agreement between the calculated and actual shrinkage is exceedingly good. The limiting shrinkage reduction for sucrose which would be attained if the solution within the cell wall became saturated is approached as a limit as the initial concentration is increased. The agreement for invert sugar is not quite so good presumably because of less efficient diffusion of the solute into the cell wall as a result of the high viscosity of the solution. The general good agreement of the experimental and calculated values of both ends of the curves indicate quite definitely that the concentrations within the cell wall certainly approach quite closely the external bulk concentrations.

The data indicate that invert sugar is considerably superior to sucrose for the antishrink treatment of wood. In both cases nothing is gained by increasing the initial concentration above 25 grams per 100 cc. of solution for this particular wood with a green density of 0.35. For high density woods this concentration should be increased somewhat. The antishrink efficiencies obtained with these sugars are superior to those obtained with the salts previously reported (8) because the curves are flatter. That is, the sugars with their high specific volume in solution show a larger reduction in the final shrinkage and a correspondingly larger relative vapor pressure at which shrinkage begins. The dimensional-change protection obtained with sugars is greatest over the relative humidity range of about 50 to 100 percent. Over the range 20 to 50 percent there is but very little protection, even when the higher concentrations of invert sugar are used. Under actual use conditions, however, the stabilization of the dimensions may be better than Figure 1 indicates because the treated wood comes to equilibrium more slowly than the untreated and hence cannot respond as readily to humidity fluctuations.

Shrinkage-moisture Content Relationships

In Figure 2 the data are plotted on the basis of surface shrinkage vs. moisture content of the dry wood. The relationship is practically linear with constant slope as previously reported for wood and wood treated with various salts (8, 9). Except near the fiber-saturation point the shrinkage seems to be a constant function of the moisture lost, irrespective of the sugar treatment. The calculated minimum moisture content for zero shrinkage was determined by multiplying the partial specific volume of water in the sugar solution when evaporation was carried to the fiber-saturation point by the moisture content of the fiber-saturation point. In each case these points fall on the extended lines through the experimental points. The specimens treated with the higher concentrations of invert sugar show a more pronounced deviation from the linear relationship at the higher moisture contents than those treated with sucrose. This is due to the excess of invert sugar deposited in the coarse capillary structure holding water at relative vapor pressures above 22 percent (3). A correction for the water held in this way by the excess invert sugar has been made for the sections in equilibrium with a relative vapor pressure of 30 percent. The corrected points represented by the square symbols practically fall on the extended straight lines. In the case of the sucrose no such correction need be made below a relative vapor pressure of 83.5 percent.

Moisture Content-relative Vapor Pressure Relationships

Figure 3 gives the moisture content-relative vapor pressure relationships. As the moisture content variation with concentration for any given relative vapor pressure condition is relatively small and shows no definite trend with changes in concentration, average values have been plotted. The curves show that the equilibrium moisture contents are only slightly increased by the presence of sugar in concentrations that will not cause deposition of sugar in the coarse capillary structure and relative vapor pressures that will not permit this sugar to take on water. In the case of the higher concentrations of invert sugar the increased moisture contents are due to water being held by the sugar in the coarse capillary structure. This is in agreement with data of Barkas (2) for 4 percent of sucrose by weight absorbed by wood, the data of Bateson (1) for 28 percent of sorbitol absorbed by wood, and the data of Leete (7) for 2 percent of invert sugar absorbed by paper. For comparison with the data of these authors the 6.25 grams of sugar per 100 cc. of solution and multiples thereof used in the treatments reported here correspond to 13 percent of sugar on the basis of the dry weight of the wood and the corresponding multiples thereof.

The data show that invert sugar in concentrations not exceeding about 25 grams per 100 cc. of solution serves as a good inexpensive antishrink agent for wood which is to be subjected to the higher ranges of relative humidity conditions. The difficulty involved in its practical use, however, seems to be in keeping the sugar in the wood and the tackey feeling that the wood assumes at high relative humidities. This can be largely avoided by minimizing the amount of sugar deposited in the coarse capillary structure.

Literature Cited

(1) Bateson, R. G. Chem. Trade J. 99:493 (1936).
(2) Barkas, W. W. Proc. Phys. Soc. 48:1 (1936). (London).
(3) Dittmar, J. H. Ind. Eng. Chem. 27:333 (1935).
(4) Hunt, G. M. Circ. 128, U. S.Dept. Agr. (1930).
(5) Pike, N. R. Paper Trade J. 102(5):39 (1936).
(6) Powell, W. Vulcanized Wood and Process of Vulcanizing Same (U. S. Patent No. 755,240). U. S. Patent Office, Off. Gaz. 109:917 (1904).
(7) Leete, J. F. Paper Mill & Wood Pulp News 58(28):21 (1935).
(8) Stamm, A. J. J. Amer. Chem. Soc. 56:1195 (1934).
(9) Stamm, A. J. Ind. Eng. Chem. 27:401 (1935).

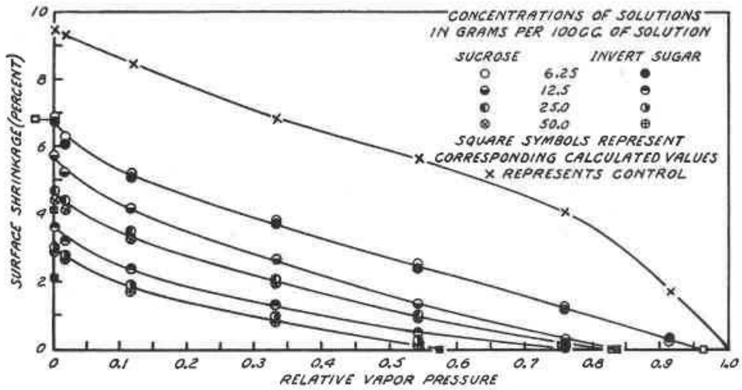

FIGURE 1. SHRINKAGE *vs.* RELATIVE VAPOR PRESSURE FOR NORTHERN WHITE PINE SECTIONS SATURATED WITH SUCROSE AND INVERT SUGAR

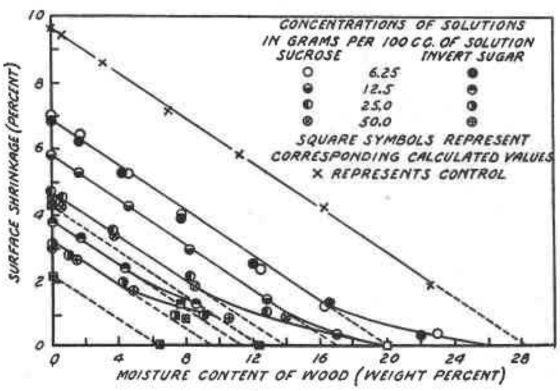

FIGURE 2. SHRINKAGE *vs.* MOISTURE CONTENT FOR NORTHERN WHITE PINE SECTIONS SATURATED WITH SUCROSE AND INVERT SUGAR

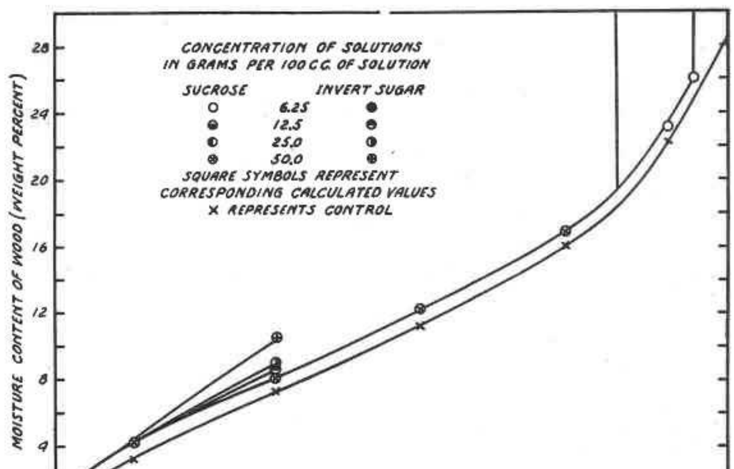

FIGURE 3. MOISTURE CONTENT *vs.* RELATIVE VAPOR PRESSURE FOR NORTHERN WHITE PINE SECTIONS SATURATED WITH SUCROSE AND INVERT SUGAR

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